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Comparative Study on Dual Parameters of Snow Cover Based on the SSG-2 Snow Water Equivalent Detection System

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Abstract: In 2024, the first SSG-2 Snow Water Equivalent Detection System in China was deployed in the outdoor experimental site for ice and snow in Jiamusi. Combined with automatic snow depth gauges and AMSR2 remote sensing products, it enabled the comparison of "dual true value" observational data during the snow accumulation period. This paper systematically evaluates the SSG-2 Snow Water Equivalent Detection System in terms of operational stability, data integrity, and data comparability. The results indicate that the overall accuracy of the SSG-2 system significantly outperforms that of the HY-SD01 and DSJ1 instruments at the same site. The true values of snow water equivalent obtained by the SSG-2 system exhibit a high degree of linear correlation with the remote sensing retrievals from AMSR2, with a high degree of synchronization in peak values, phases, and patterns of change, enabling rapid proportional calibration of satellite products. This study is the first to achieve refined validation of remote sensing retrievals using automatically obtained true value data for snow water equivalent. Subsequent research should utilize multi-year, multi-site data to validate its seasonal stability and regional applicability.

Keywords: SSG-2; Snow water equivalent; Comparative analysis

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1. Preface

Snow depth, snow density, and snow water equivalent (SWE) are not only key parameters in hydrological, meteorological, and climatic models in cold regions but also core variables for understanding changes in the global climate system, regional water resource evolution, and extreme disaster response mechanisms. Against the backdrop of global warming, snow cover, as an important component of the cryosphere, is undergoing significant changes in its spatial and temporal distribution characteristics and trends, directly affecting the surface energy balance, land-atmosphere interactions, and ecosystem stability. Therefore, improving the observational accuracy of snow cover parameters, especially achieving high spatial and temporal resolution, automated, and true valuelevel acquisition of snow water equivalent, holds significant scientific importance for deepening the understanding of land surface processes in cold regions, optimizing the expression of physical mechanisms in climate models, and enhancing adaptability to climate change. In addition, snow water equivalent directly reflects the potential volume of snowmelt runoff and serves as a crucial basis for decision-making in spring flood warnings, reservoir operations, agricultural irrigation, and urban water supply management. In high-latitude regions, frequent snowmelt-induced flooding events in spring pose severe threats to the safety of people's lives and property.

Common methods for measuring snow water equivalent include ground-based measurements and microwave remote sensing. Traditional ground-based measurements involve manual weighing, which is not only time-consuming and labor-intensive but also lacks timeliness. Microwave remote sensing offers large observation scales and high temporal resolution but suffers from inadequate spatial resolution. These limitations make it difficult to meet the modern demands for timely and high-precision data in disaster prevention and mitigation. Therefore, the development of automatic snow water equivalent observation technology with "millimeter-level accuracy, hourly resolution, and year-round unattended operation" capabilities can significantly enhance the modernization of snow cover monitoring. It also provides critical ground-truth support for remote sensing inversion algorithms, thereby promoting the integration of multi-source data and improving disaster warning capabilities. This technology holds significant social service value and promising prospects for widespread application. This paper aims to verify the stability of the snow water equivalent detection system, as well as the integrity and accuracy of its data, while establishing new methods for observing snow disaster weather. It seeks to form an observational experimental dataset, providing a scientific basis for short-term and imminent forecasting, numerical prediction, and disaster prevention and mitigation, as well as offering data support for inversion algorithms.

2. Experimental content

The experiment was conducted from winter 2024 to spring 2025 at the Jiamusi National Comprehensive Meteorological Observation Special Experimental Field. An observational product dataset was established, encompassing snow density, snow depth, and snow water equivalent measurements from instruments such as the SSG-2 snow water equivalent detection system, automatic snow depth gauges, and microwave remote sensing-derived snow water equivalent data from meteorological satellites during the snow accumulation period. A thorough analysis of multi-source data was performed to calculate and evaluate data integrity and comparability. Origin 2024 was used for graphical representation.

2.1. Equipment models and data collection instructions

2.1.1. Snow water equivalent detection system (SSG-2)

The snow water equivalent detection system consists of a data acquisition unit, a snow characteristic analyzer unit, a snow depth sensor unit, and a data transmission unit. The data is categorized into daily data and half-hourly data. Snow depth: The principle of the measurement sensor is to calculate the snow depth based on the transmission time of ultrasonic waves between the sensor and the snow surface. Snow water equivalent: The weight of the snow on the snow pillow can be measured using a load cell embedded in the snow pillow to obtain the snow water equivalent. Additionally, by combining the snow depth measured by the snow depth sensor on the snow pillow, the snow density can be calculated.

2.1.2. Automatic snow depth gauges

(1) Beijing Huayun Shengda HY-SD01 Snow Depth Observer, (2) Beijing Huayun Shengda DSJ1 Snow Depth Observer. The device data is stored on the SD card of the data collector and is periodically read and backed up to a computer using a card reader. According to the "Specification for Automatic Surface Meteorological Observation" (First Edition) (Document No. Qichenghan [2019] No. 154), snow depth is measured in centimeters (cm) and rounded to the nearest integer.

2.2. Manual observation data

According to the "Specification for Surface Meteorological Observation" (2003 Edition), on days suitable for observing snow depth, at 08:00 daily, a snow measuring ruler is vertically inserted into the snow at the observation site until it reaches the ground surface (without being inserted into the soil). Based on the scale markings on the ruler obscured by the snow surface, the snow depth is read to the nearest integer in centimeters, with decimals rounded up or down. Three measurements must be taken during each observation, and their average is calculated.

2.3. Snow water equivalent data retrieved through microwave remote sensing by meteorological satellites

In this experiment, the daily average snow water equivalent data from the SSG-2 Snow Water Equivalent Detection System are compared and analyzed with the snow water equivalent data retrieved through satellite remote sensing. The remote sensing retrieval data is obtained using the microwave snow water equivalent from the Advanced Microwave Scanning Radiometer 2 (AMSR2) onboard the Global Change Observation Mission for Water-1 (GCOM-W1) satellite.

3. Experiment evaluation

3.1. Evaluation of equipment operational stability

During the observation and testing period, the observation site's detection environment, snow water equivalent detection system, and automatic snow depth observer were inspected daily to ensure stable equipment operation. Weekly, automatic snow depth data were collected to verify their completeness and consistency with manually observed values. In cases of significant discrepancies, the causes were promptly investigated, the manufacturer was contacted for maintenance, and detailed records of the maintenance process were kept. After the test, a comprehensive evaluation of the instrument's operational stability was conducted, summarizing daily maintenance procedures and operational requirements. The evaluation determined whether the equipment could be formally put into operational use, providing technical support for its operational deployment.

Daily inspection precautions: (1) Check for obstructions at the emission port of the snow depth observer to prevent measurement failures and missing data caused by foreign object blockages, or reading jumps due to attenuated echo signals, resulting in "negative snow depth" or abnormally high values. (2) After snowfall, promptly clear accumulated snow from the solar panels of the SSG-2 snow water equivalent detection system to prevent system power depletion and data interruption. If the battery undergoes deep discharge, its lifespan may be shortened, and it may freeze and crack under low temperatures. Accumulated snow may partially melt during the day and refreeze at night, forming ice layers that are difficult to remove and may even crack the glass or create hot spots, burning out the components.

The evaluation period was set during the snow accumulation period in the urban area of Jiamusi, from

November 6, 2024, to March 27, 2025, totaling 142 days. Under low-temperature, high-wind, and snowy conditions, the Beijing Huayun Shengda DSJ1 snow depth observer and SSG-2 snow water equivalent detection system operated smoothly without malfunctions, demonstrating excellent stability. However, the Beijing Huayun Shengda HY-SD01 snow depth observer experienced sensor failure early on, rendering the data unusable. The manufacturer promptly replaced the snow depth sensor and upgraded the collector program. Therefore, the data evaluation period for this instrument was from system stabilization to the end of the snow accumulation period, i.e., from November 29, 2024, to March 27, 2025, totaling 119 days. However, the system experienced a failure from March 18 to 27, accounting for 10 days of downtime.

3.2. Quality analysis of snow depth data

3.2.1. Data integrity

The datasets from three sets of snow depth observation equipment during the snow accumulation period have been collated. The statistical results of the data are shown in **Table 1**.

Table 1. Data integrity of equipment

Equipment Name	Data Type	Expected Reports	Actual Reports	Missing Rate (%)	Reporting Rate (%)
SSG-2 Snow Water Equivalent Detection System	Daily Data	142	142	0	100
	30-min Data	6816	6816	0	100
HY-SD01 Snow Depth Detector	Daily Data	119	108	11	91
DSJ1 Snow Depth Observer	Daily Data	142	142	0	100

Snow accumulation period: From November 6, 2024, to March 27, 2025, totaling 142 days. The arrival rates of daily and half-hourly data from the SSG-2 Snow Water Equivalent Detection System and the daily data arrival rate of the Beijing Huayun Shengda DSJ1 Snow Depth Observer are all 100%, with no missing data. For the Beijing Huayun Shengda HY-SD01 Snow Depth Observer, the data was empty on December 31, 2024, and from March 18 to March 27, 2025. After troubleshooting with the manufacturer, it was found that the data missing on December 31 was due to a software time setting issue, while the absence of data from March 18 to 27 was caused by a system failure.

3.2.2. Data comparability

Manual observations are conducted at 08:00 each day. To ensure the accuracy and effectiveness of data comparability analysis, the three automatic snow depth observers also use snow depth data collected at the same time as manual observations. During the snow accumulation period, the changing trends of snow depth observation data from the three snow depth observers are relatively consistent with the manually observed values. Except for the DSJ1 Snow Depth Observer, which showed data jumps between January 20 and February 7 without significant snowfall, resulting in large differences from the manual data, with a maximum difference of 10 cm, the other two instruments, the SSG-2 Snow Water Equivalent Detection System and the HY-SD01 Snow Depth Observer, showed good agreement with the manual data and were slightly lower than the manual observations (**Figure 1**).

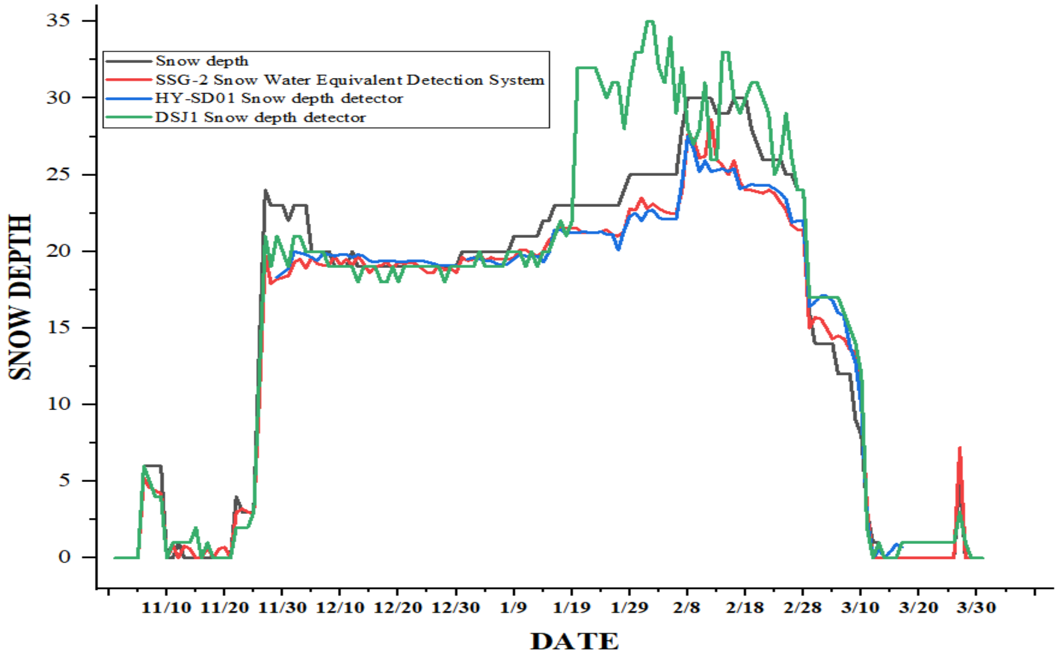

Figure 1. Time series plot of manual and automatic snow depth observations

Linear fitting was performed on the data from the three sets of equipment and the manually observed snow depth (**Table 2** and **Figure 2**). The results showed that:

(1) The linear correlation (Pearson r) of the SSG-2 Snow Water Equivalent Detection System is 0.990, indicating an almost perfect linear relationship and optimal performance. The slope is approximately 0.90, slightly on the lower side, resulting in a slight underestimation. The goodness of fit (R^2) is 98%, indicating the best fit with minimal differences between observed values and the fitted line. The small sum of squared residuals suggests no significant systematic bias, indicating good data quality and a robust model.

(2) The DSJ1 Snow Depth Observer has an r value of 0.964, demonstrating good correlation. The slope is approximately 1.05, very close to the ideal value of 1, indicating minimal systematic error. The R^2 value is 92.6%, indicating a good fit. However, the sum of squared residuals is significantly higher than the other two models, suggesting greater dispersion in the observed data and slightly poorer stability.

(3) The HY-SD01 Snow Depth Observer has an r value of 0.934, indicating a strong correlation, albeit relatively weaker. The slope is approximately 0.79, resulting in a significant underestimation and a considerable systematic bias. The R^2 value is 87.3%, indicating a relatively poorer fit. The points exhibit significant dispersion, with a wide confidence band and an overall deviation from the line y = x, indicating a clear underestimation.

Comprehensive analysis: The correlation coefficients of all three devices are above 0.96, indicating an extremely strong linear correlation between the measured values and the true values. The SSG-2 Snow Water Equivalent Detection System demonstrates the best performance in terms of linearity, accuracy, and stability. The DSJ1 has the most ideal slope, with a measurement ratio closer to the true value. The HY-SD01 performs moderately across multiple indicators, exhibiting underestimation and high intercept phenomena, requiring careful calibration during use.

Table 2. Comparability of equipment data

Instrument Name	Intercept (a)	Slope (b)	Pearson r	R^2 (COD)	Adjusted R^2	Residual Sum of Squares
SSG-2 Snow Water Equivalent Detection System	0.56161	0.89699	0.99001	0.9801	0.9801	263.64
HY-SD01 Snow Depth Detector	3.10998	0.79119	0.93435	0.8734	0.9037	223.49
DSJ1 Snow Depth Observer	0.17961	1.04675	0.96353	0.9257	0.9262	1903.47

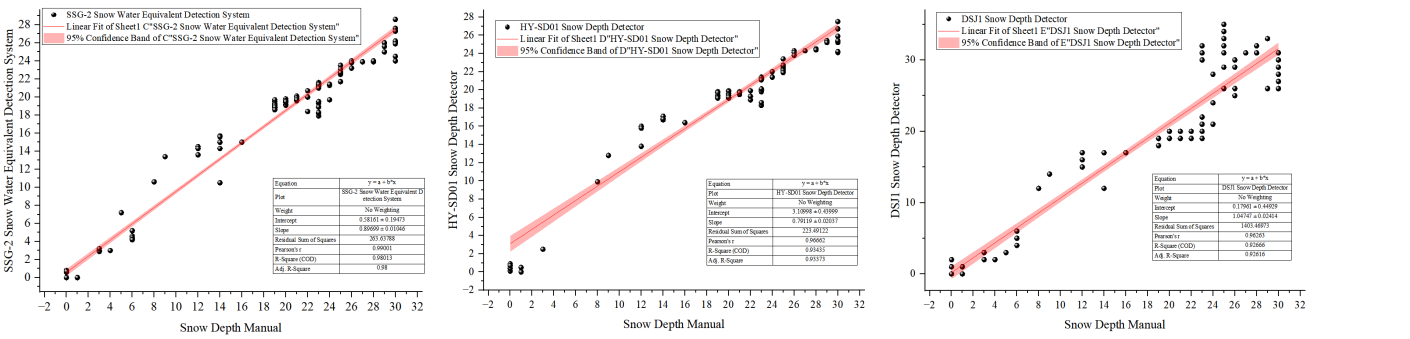

Figure 2. Linear fitting between three sets of snow depth observation instruments and manually observed snow depth

3.2.3. Analysis of snow water equivalent data quality

There are two primary methods for snow monitoring via satellite remote sensing: optical snow cover monitoring and microwave retrieval of snow depth and snow water equivalent. Passive microwave remote sensing is currently the most effective method for retrieving snow depth and snow water equivalent [2–3]. Due to its ability to observe regardless of sunlight and its all-weather capability, passive microwave remote sensing data from meteorological satellites are suitable for retrieving monitoring products of land surface water, such as precipitation, soil moisture content, and snow cover [4–5].

By comparing the snow water equivalent (SWE) detection system data with remotely sensed retrieval data and conducting linear fitting (as shown in **Figures 3** and **4**), the following conclusions were drawn: (1) The remotely sensed retrieved SWE data showed a rapid increase from January to February, followed by a decline in March, with an amplitude significantly greater than that of the SSG-2 SWE detection system. 2. There was a high degree of linear correlation, with a slope of approximately 1.98, $R^2 = 0.766$, and r = 0.875. The remotely sensed retrieval data exhibited an almost 2:1 amplification relationship with the SWE detection system data, allowing for mutual conversion through a linear equation. The conversion formula is as follows: the SWE detection system data is approximately (remotely sensed retrieval data − 1.18) / 1.98, which is roughly equivalent to dividing the remotely sensed retrieval data. In real-time operations, dividing the remotely sensed retrieval value by 2 yields SWE data with the same dimension as that from the SSG-2 SWE detection system. However, due to the limited time span of the samples, this conversion relationship was proposed based solely on a single winter scenario in this study. Its universality and stability in real-time applications still require further validation and calibration through independent observational data from multiple years and snow accumulation cycles. (3) The two sets of data were highly coupled in terms of "peak magnitude—occurrence time—change rhythm"; their combined use can effectively reduce the uncertainty of single-source retrieval without increasing additional observational costs, providing an error compensation mechanism for high-precision estimation of SWE and simulation of snowmelt processes.

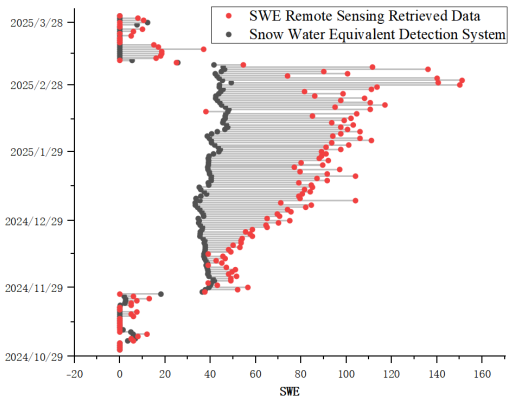

Figure 3. Time series diagram of the SWE detection system and remotely sensed retrieval data

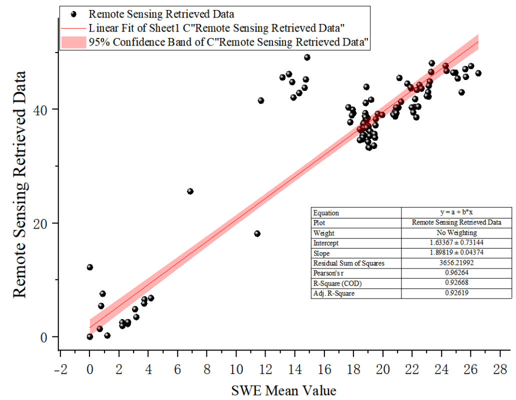

Figure 4. Linear fitting of remotely sensed retrieval data and the SWE detection system

4. Innovation

The first set of SSG-2 SWE detection systems in China was deployed at the Jiamusi Ice and Snow Experimental Site, where a complete dataset of snow depth and SWE during the snow accumulation period from the 2024 Winter Solstice to the spring of 2025 was collected. The experiment comprehensively evaluated the performance of the SSG-2 SWE detection system from three aspects: system stability, data integrity, and data comparability. In response to issues identified during operation, multiple collaborative debugging sessions with the manufacturer were conducted, resulting in four rounds of optimized data transmission and processing code, significantly enhancing system reliability and data usability.

The SSG-2 Snow Water Equivalent (SWE) Detection System directly provides the true value of SWE by measuring the weight of snow accumulation on the snow pillow using weighing sensors. The true value of snow depth is obtained through manual snow depth observations (averaging three readings). The combination of these two methods forms a ground-based "dual true value" benchmark, providing an independent and reliable validation benchmark for remote sensing retrieval and assimilation algorithms. This experiment is the first to directly compare and analyze the true value of SWE with remote sensing retrieval results, achieving refined validation of satellite products using ground truth values.

5. Conclusion

Comprehensive performance evaluation of the SSG-2 snow water equivalent detection system: The system operated stably during the snow accumulation period from November 2024 to March 2025, with a daily data reporting rate of 100% and no missing half-hour data. Compared to manual snow depth measurements, it outperformed the concurrent HY-SD01 and DSJ1 automatic snow depth gauges in terms of Pearson correlation coefficient, goodness of fit, sum of squared residuals, and overall accuracy, meeting the conditions for operational deployment. Linear Regression Slope: The linear regression slope between the SSG-2 SWE Detection System and manual observations is 0.90, indicating a slight underestimation that can be eliminated through univariate calibration. The DSJ1 snow depth gauge exhibits the best slope performance, with a ratio closest to 1:1, but with high dispersion. The HY-SD01 snow depth gauge has a slope of only 0.79, indicating significant underestimation and requiring recalibration.

Snow water equivalent data: The remotely sensed SWE data retrieved from AMSR2 show a high linear correlation with the true values from the SSG-2 SWE Detection System ($r = 0.875$, $R^2 = 0.766$). The two datasets are highly synchronized in terms of peak magnitude, occurrence time, and change rhythm. The remotely sensed values are approximately twice the ground truth values, with a conversion formula of SWE_truth ≈ AMSR2 / 2, providing a rapid proportional correction for satellite products.

6. Existing issues and improvement directions

Data storage: Since the snow depth gauge is in the experimental stage, raw data is only written to the onboard memory card, requiring periodic reading of the memory card. Without 4G or Ethernet connectivity, real-time data transmission and online monitoring are not possible, making it difficult to promptly detect and handle anomalies, which can reduce data quality. It is recommended to add an IoT module to support online monitoring and immediate anomaly alerts.

Data format and processing: The data formats and temporal resolutions of various snow depth sounders vary. Before conducting data comparisons, it is necessary to apply formulas to calculate snow depth values, then standardize the timing sequences and file structures. The workload for preliminary data preprocessing is substantial, making it currently impossible to achieve real-time data visualization and online analysis. There is a need to develop preprocessing scripts for automatic parsing and quality control to reduce manual preprocessing efforts.

Sample extrapolation: The remote sensing-ground proportional relationship is based on data from a single winter. Subsequent efforts should utilize multi-year, multi-site data to verify its seasonal stability and regional applicability.

Disclosure statement

The authors declare no conflict of interest.

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